ABSTRACT

of the dissertation for the degree of Doctor of Philosophy (Ph.D.)
in "6D061100 - Physics and Astronomy"

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Formation and evolution of Open clusters

General description of the work

The dissertation focuses on the evolution of Open clusters formed in cold dense molecular gas clouds. The numerical models of gravitationally bound clusters formed with low star formation efficiency that do not dissolve due to gas expulsion are presented.

Relevance of the topic

The evolution of the visible universe since the Big Bang is closely related to stars. Understanding the mechanisms of star formation and evolution can help us to know more about the evolution of the Universe. The fact that stars do not form one by one, but in clusters, is the only phenomenon that sheds light on the star formation history of galaxies. However, during evolution, the star clusters undergo many changes from their original state and even dissolve in the tidal field of the parent galaxy. Such changes prevent the accurate reading of the history of star formation by observing star clusters. Therefore, a comprehensive study of the mechanisms of formation, evolution, and dissolution of star clusters is one of the most actual problems today. In particular, the launch of the James Webb Space Telescope, which sees clusters of the farthest galaxies, urges us to solve these problems.

Star clusters are formed in dense molecular clouds as a result of the collapse of cold gas clumps. The feedback from the massive stars, in which thermonuclear reactions have begun, heats and ionizes gas clouds around, and blows them with radiation pressure and stellar winds. Thus, molecular gas blown at a speed of about 10 km/h leaves the cluster within about a million years. With gas expulsion, most of the initial mass of the cluster is gone, and the stellar cluster is not in virial equilibrium anymore, thus the violent relaxation begins. During violent relaxation, the mass and shape of the star cluster undergo various changes depending on the formation conditions. All this has a significant impact on the further evolution of the cluster.

It is important to take such effects into account when modeling the formation and evolution of star clusters. In addition, models must be able to describe not only one or two special cases but also models of star clusters in a wide range of parameter space. The relevance of the dissertation is in the development of a numerical model of the long-term evolution of clusters, taking into account the formation conditions in a wide range of parameter space and considering ways to solve practical problems using this new model.

The purpose of the work

To develop a numerical model that conceives all evolutionary stages of Open clusters from formation to dissolution and to apply this model to a possible explanation for some of the observed phenomena.

Objectives of the study

1. To develop a new model of stellar clusters using Dehnen density profiles to better describe the structure of very young clusters.

2. To study the effect of the inner slope of the Dehnen density profile on the evolution of the star cluster after the period of intensive relaxation.

3. To apply the proposed model to explain the dispersion measure of fast radio bursts.

Objects of research: stellar clusters formed with constant efficiency per free-fall time in a centrally concentrated spherically symmetric gas cloud.

The subject of research is the dynamical evolution of stellar clusters and the effect of different parameters of the cluster on them.

Research method

Numerically solving the differential equations, direct integration of the N-body problem with the fourth-order Hermit integrator, parallel calculations with phi-GRAPE/GPU code using CUDA/C, MPI, OpenMP technologies, processing large datasets in Python with NumPy, SciPy, and Pandas packages.

Conclusions for the defense

1. The use of the Denen model as the initial density profile in N-body simulation of the stellar cluster reduces the minimum star formation efficiency sufficient to survive the instantaneous gas expulsion from the previously obtained 15% to 3%, which is in good agreement with observations.

2. The higher the slope of the inner stellar density profile the more the gravitationally bound mass fraction is kept after violent relaxation.

3. The 80% of young neutron stars, which are possible sources of fast radio bursts, do not leave the cluster further than 100 parsecs, therefore, the interaction of the radiation of these bursts with the ionized gas of the star formation region can make a significant contribution to the large value of their dispersion measure.

The scientific novelty of the work is that for the first time

1. it was shown that Dehnen models can be adequately applied to stellar clusters and that they can effectively describe the newly formed gas-embedded clusters;

2. a double-slope density profile and updated stellar evolution algorithms were used to model Open clusters;

3. the distribution of core-collapse supernovae remnant neutron stars around the parent cluster, while they are sufficiently young to be a possible source of fast radio bursts, was studied.

The theoretical and practical significance of the work

The results of the dissertation allow us to understand the history of the star formation of galaxies by studying the formation and evolution of stellar clusters. In addition, the methods of parallel computing developed in the course of work can be used in various fields. And big data processing tools developed in the analysis of the output data of computer simulations can be adapted not only in the field of astronomy but also in any field that works with big data.

Personal contribution of the author

The author is fully involved in research at all stages of the dissertation. The

author played a key role in the problem statements, preparation of initial conditions, and processing of output data of computer simulations. Performing computer simulations was a lot of work, so it was shared with some collaborators. The analysis of reports and results was carried out jointly with supervisors, as well as domestic and foreign collaborators

Reliability and validity of results

The results and conclusions obtained during the study reflect the content of all sections and are confirmed by the publication of the main scientific results in peer-reviewed international and domestic scientific journals, including a highly rated journal included in the 1st quartile (Q1) of the Web of Science and Scopus databases.

Approbation of work

The results of the dissertation were published in three articles and several international conference proceedings. In particular:

in high impact factor journals in the Clarivate (Web of Science) database and the Scopus international scientific database:

1. Shukirgaliyev, B., Otebay, A., Sobolenko, M., et al. Bound mass of Dehnen models with a centrally peaked star formation efficiency // Astronomy & Astrophysics. - 2021. - Vol. 654. - P.A53. [**Q1, Impact Factor =5.803, 85%**]

in journals recommended by the Control Committee for Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan:

1. Shukirgaliyev, B., Otebay, A., Just, A., et al. Violent relaxation in isolated star clusters // News of the National Academy of Sciences of the Republic of Kazakhstan, Physico-mathematical series. – 2019. – Vol. 3. – № 325. – P. 130.
2. Otebay, A., Kalambay, M., Shukirgaliyev, B. How far can get FRB progenitor neutron stars from their birthplace? // Recent Contributions to Physics. – 2021. –Vol.4. – №79. – P. ***in the conference proceedings:***
1. Өтебай А.Б., Қаламбай М.Т., Шукиргалиев Б.Т. Оқшауланған жұлдыздық шоғырлардағы қарқынды релаксация. //“Фараби Әлемі” атты халықаралық ғылыми конференция тезистер жинағы - Алматы, 2019.-277 бб.
2. Бегалы З., Өтебай А.Б., Қаламбай М.Т. Жұлдызтүзу тиімділігінің шоғырдың бастапқы тығыздық профиліне тәуелділігі. //“Фараби Әлемі” атты халықаралық ғылыми конференция тезистер жинағы – Алматы, 2020.-275 бб.
3. Өтебай А.Б., Бегалы З., Қаламбай М.Т., Шукиргалиев Б.Т. Жұлдыздық шоғырлардың тығыздық профильдері мен лездік газ ығыстырудан кейінгі өмірсүргіштігі. //“Фараби Әлемі” атты халықаралық ғылыми конференция тезистер жинағы – Алматы, 2020.-307 бб.
4. Абдраманова А.Е., Өтебай А.Б., Тлеубек А.Н., Әбдінәсілім А.Т., Гравитация арқылы байланысқан жұлдыздық шоғырланулардың динамикасын сандық моделдеу. //“Фараби Әлемі” атты халықаралық ғылыми конференция тезистер жинағы – Алматы, 2021.-274 бб.
5. Өтебай А.Б., Қаламбай М.Т., Шукиргалиев Б.Т., Жұлдыздық шоғырдың ерте өлімін тоқтатуда көлбеулігі жоғары жұлдыз түзу тиімділік профильдің әсері. //“Фараби Әлемі” атты халықаралық ғылыми конференция тезистер жинағы – Алматы, 2021.-214 бб.
6. Әбдінәсілім А.Т., Нұржұма М.М., Тыныштық А.Б., Өтебай А.Б.

Сандық есептеуден шыққан жұлдызды шоғырлар аспан сферасындағы көрінісі // «Фараби Әлемі» атты халықаралық ғылыми конференция тезистер жинағы – Алматы, 2022.-182 бб.

Relation of the dissertation topic with the plans of scientific works

Results and methods obtained in the dissertation in accordance with the plan of research are used in the implementation of the project AP08856149 entitled "Dissolution mechanisms of star clusters in the Milky Way-like galaxies" from the MES RK in the framework of the "Grant funding for scientific and (or) scientific and technical projects for 27 months 2020-2022".

The scope and structure of the thesis.

The thesis consists of an introduction, 4 sections, conclusion and list of references from 222 titles, contains 100 pages of basic computer text, including 29 figures, 93 formulas and 1 table.